# Listening to the Heliosphere: Making Space Data Audible for Citizen Science

Michael Hartinger and many co-authors from the “Heliophysics Audified: Resonances in Plasmas” team

Special thanks to Martin Archer and Emmanuel Masongsong, who provided significant material for this talk

HamSCI Workshop, March 18, 2023

This project is based on work supported by NASA under award 80NSSC21K0796

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Help us identify plasma waves in spacecraft data:

listen.spacescience.org

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# Why don’t Heliophysics researchers use audio analysis?

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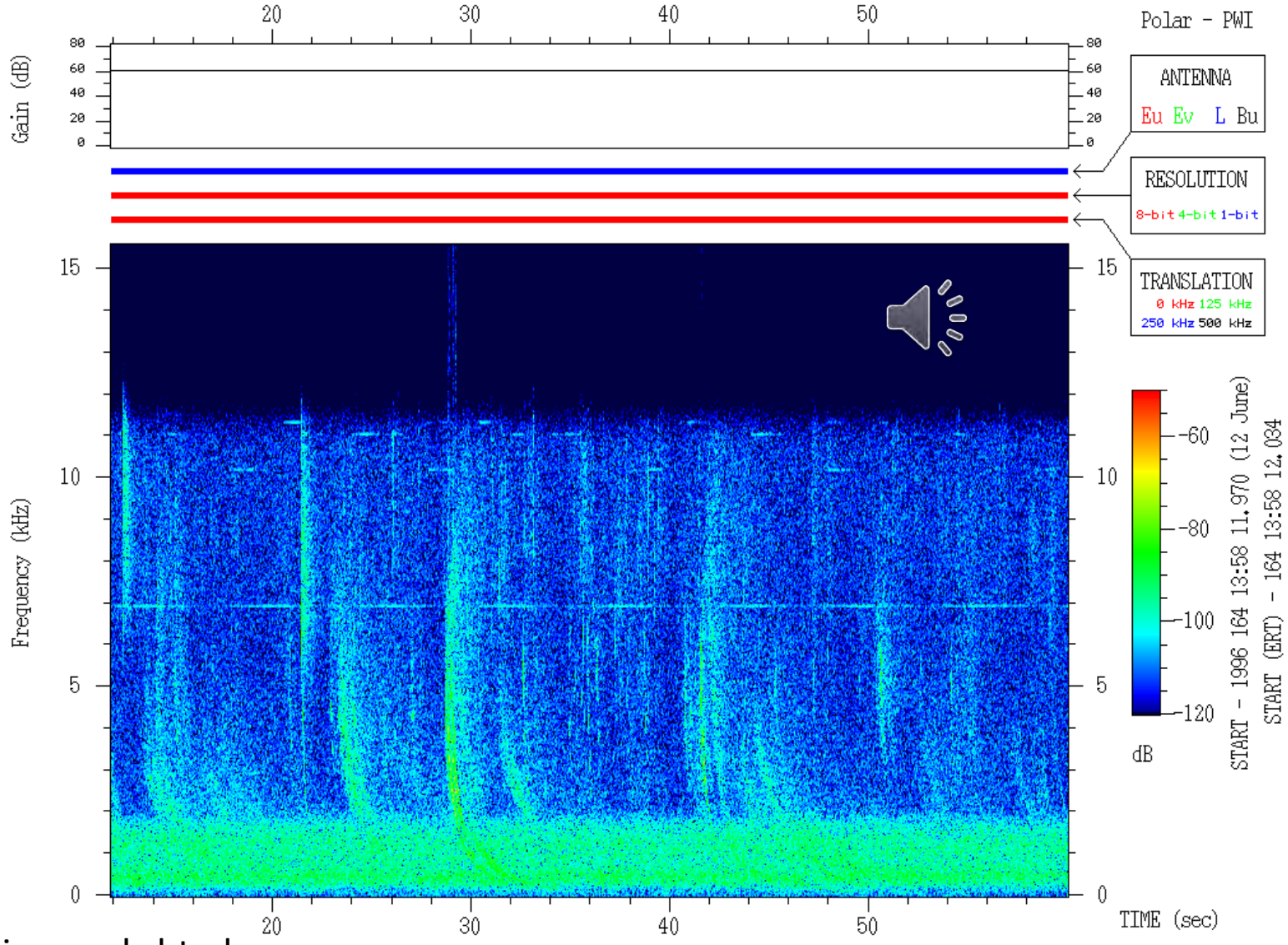
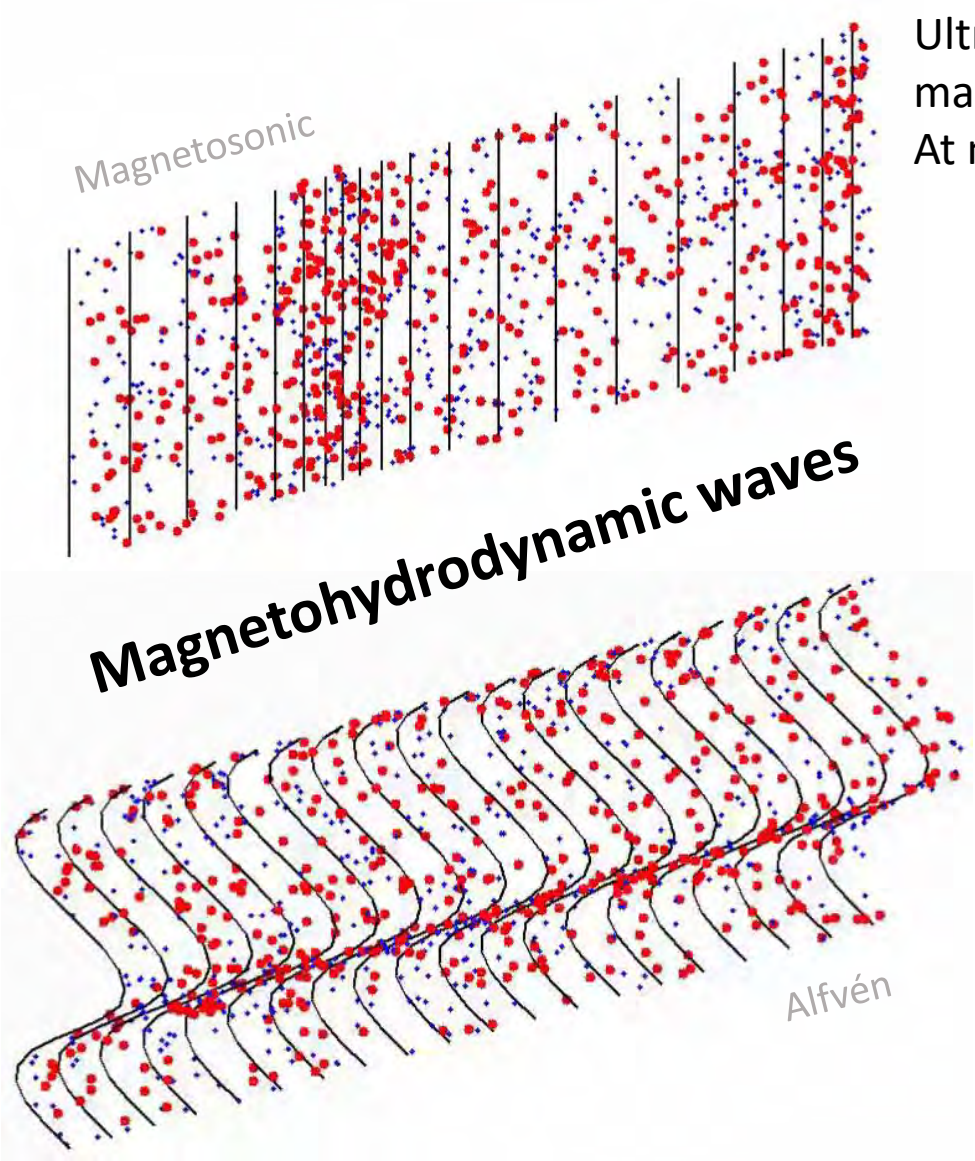
# Why did Heliophysics researchers stop using audio analysis?

- “Chorus”, “Hiss”, “Whistlers”,…
- Plasma waves with frequencies in the human audible range were identified and classified based on the sounds they made when played through a speaker
- Audio analysis is less frequently used now apart from public outreach
  **[Exception: ham operators!]**



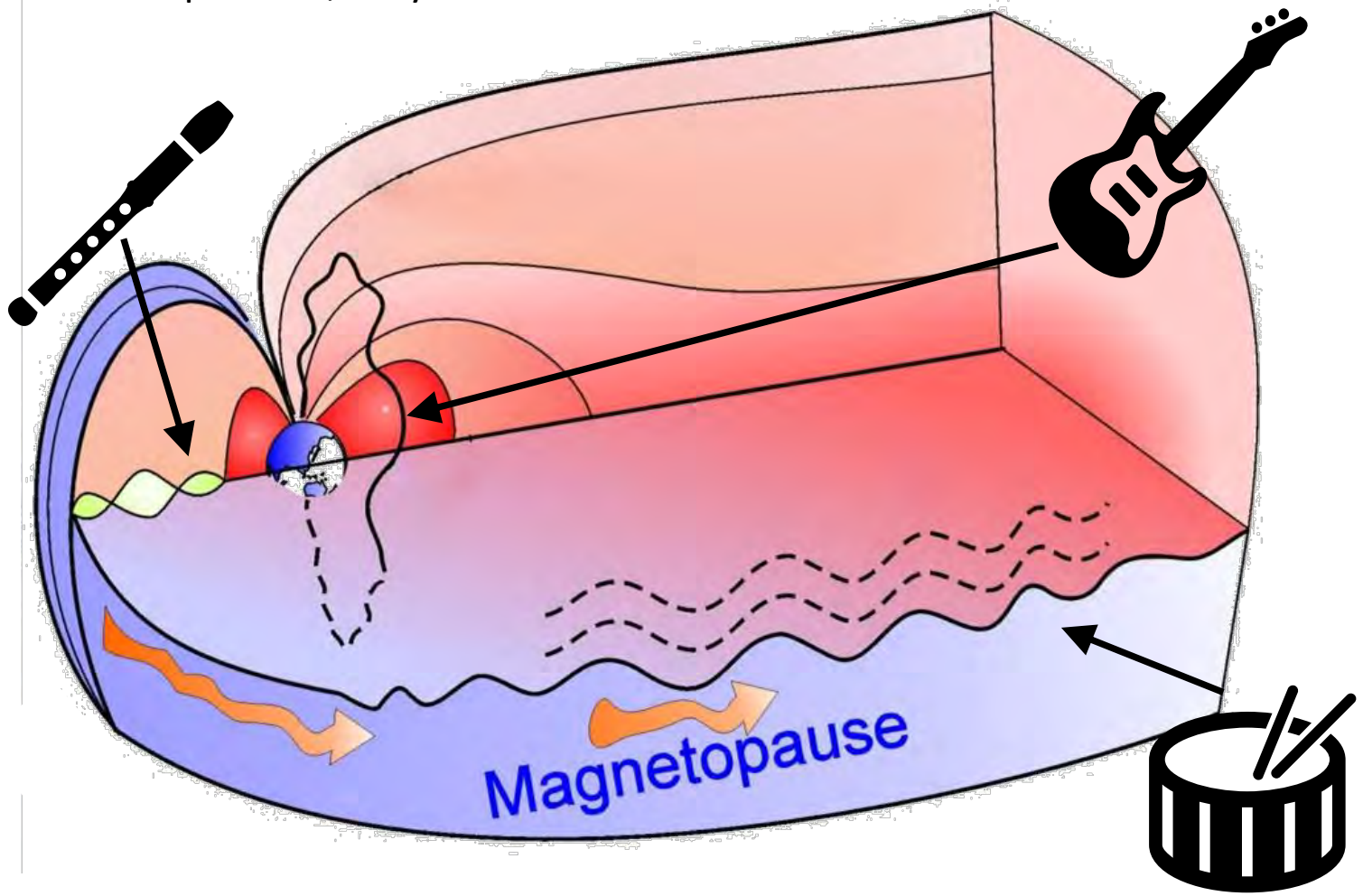

Credit: Don Gurnett, University of Iowa, NASA, https://pwg.gsfc.nasa.gov/istp/polar/polar_pwi_sounds.html

# Magnetospheric ULF waves




Ultra Low Frequency (ULF) waves = the lowest frequency plasma waves the Earth's magnetosphere can support

At milliHertz frequencies, they form resonances like in musical instruments




**Satellites provide *in situ* time-series measurements of these waves**

# Audification of ULF waves

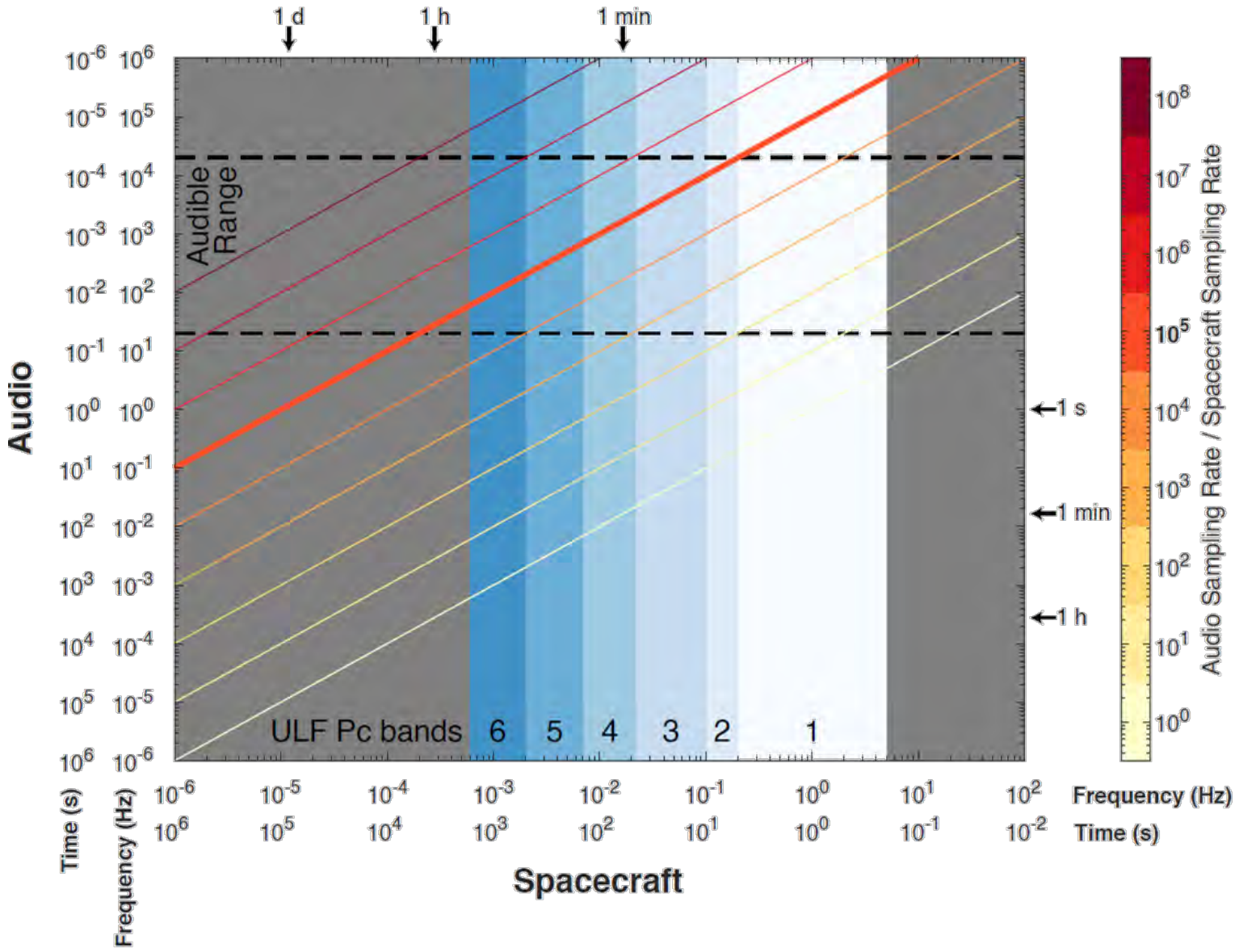
Human hearing has benefits over visual analysis

- Dynamic range
- Sensitivity
- Nonlinear

Can make ULF wave bands audible simply by speeding up their playback (1 year → 6 min)

Identify complex but repeatable patterns that visual analysis and automated detection algorithms miss

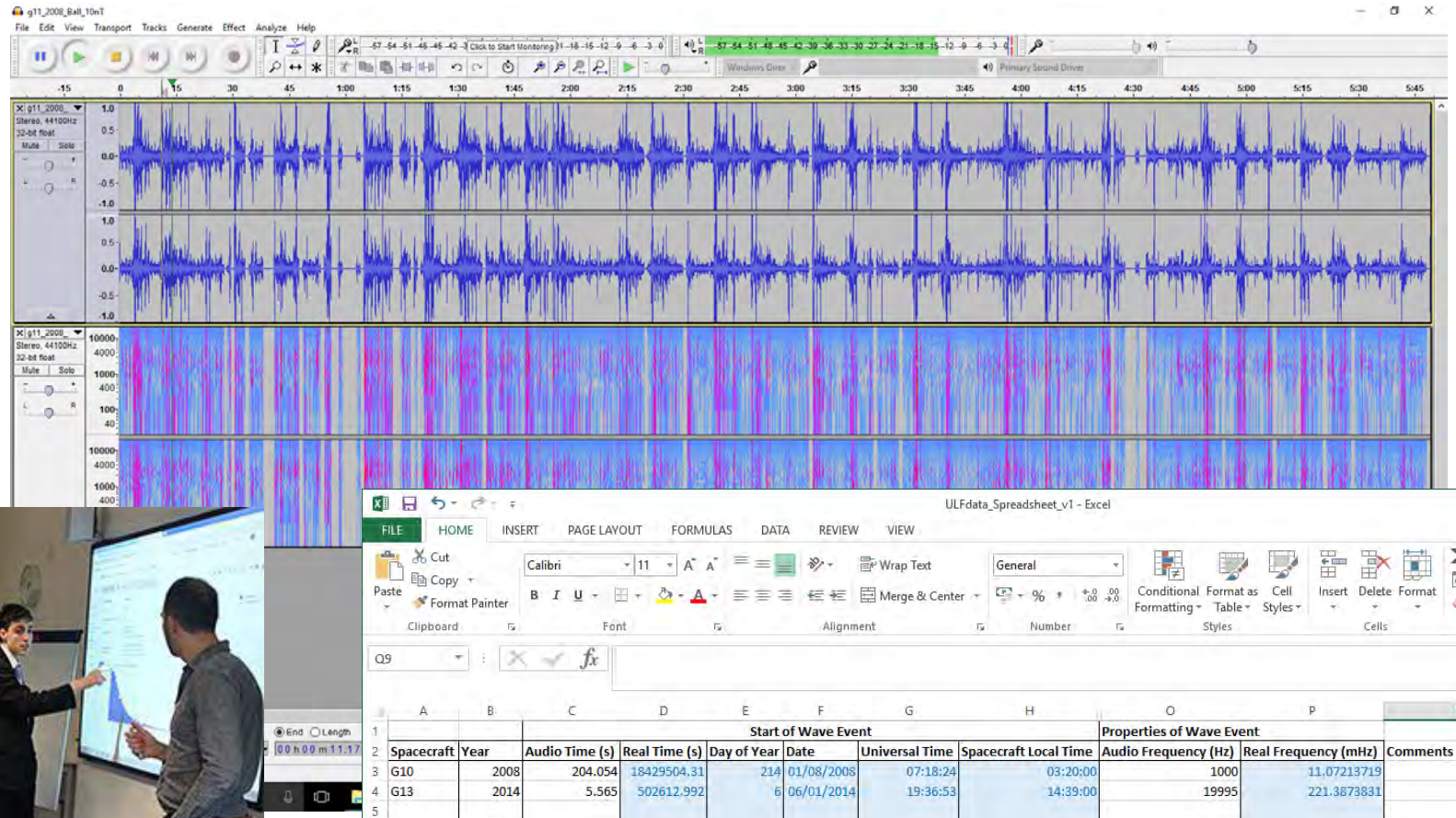
Application to GOES magnetometer data



# Getting the Public Involved with Research

**UK project with London High Schools. Audio released to schools as part of exploratory (not prescribed) projects. Students discovered a recurring type of ULF wave activity with results published in the journal *Space Weather***

Magnetospheric
Undulations
Sonified
Incorporating
Citizen
Scientists



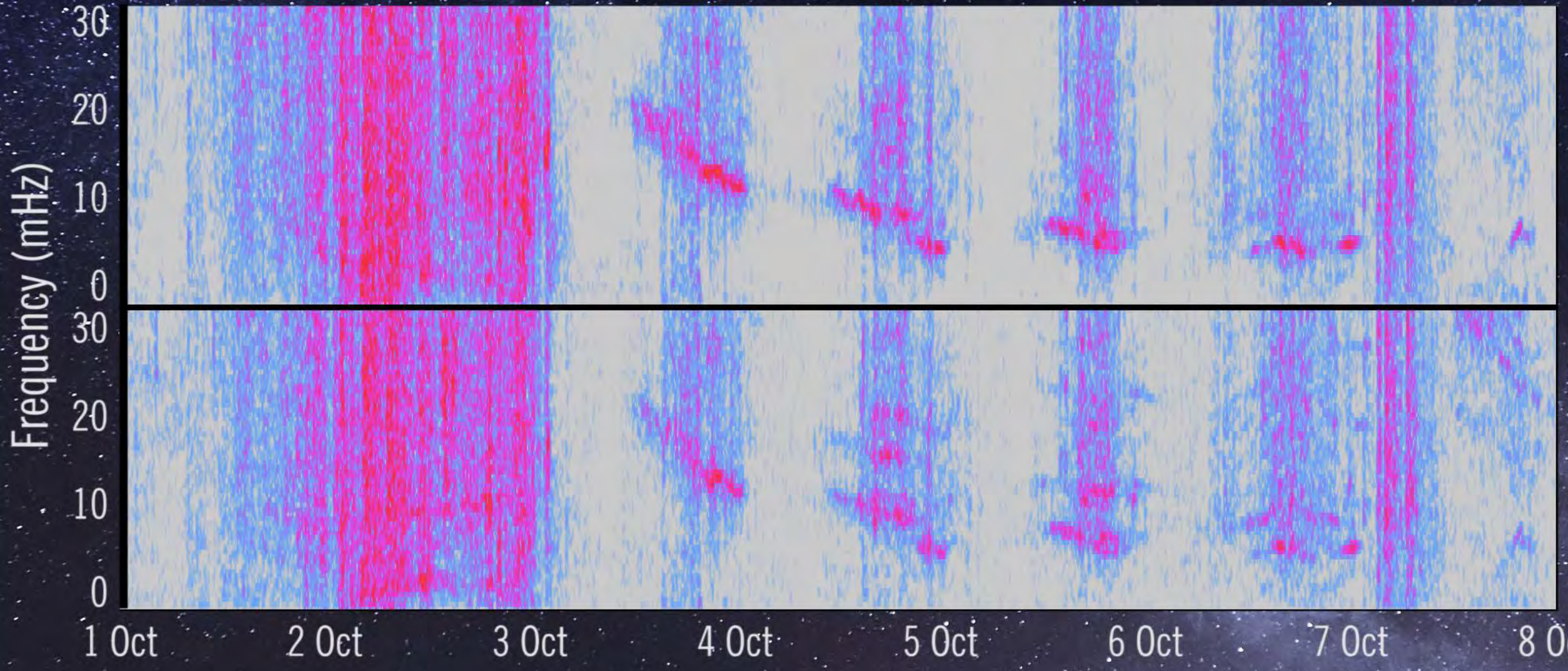
ULFdata_Spreadsheet_v1 - Excel

| | A | B | C | D | E | F | G | H | O | P | Q | R | S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | Start of Wave Event | | | | | | Properties of Wave Event | | | | |
| 2 | Spacecraft | Year | Audio Time (s) | Real Time (s) | Day of Year | Date | Universal Time | Spacecraft Local Time | Audio Frequency (Hz) | Real Frequency (mHz) | Comments about event | *** ADD YOUR OWN ( | |
| 3 | G10 | 2008 | 204.054 | 18429504.31 | 214 | 01/08/2008 | 07:18:24 | 03:20:00 | 1000 | 11.07213719 | | | |
| 4 | G13 | 2014 | 5.565 | 502612.992 | 6 | 06/01/2014 | 19:36:53 | 14:39:00 | 19995 | 221.3873831 | | | |
| 5 | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | |
| 11 | | | | | | | | | | | | | |

Data Table | Setup

READY

# School Students Identify Sounds of Earth's Magnetic Shield Recovering



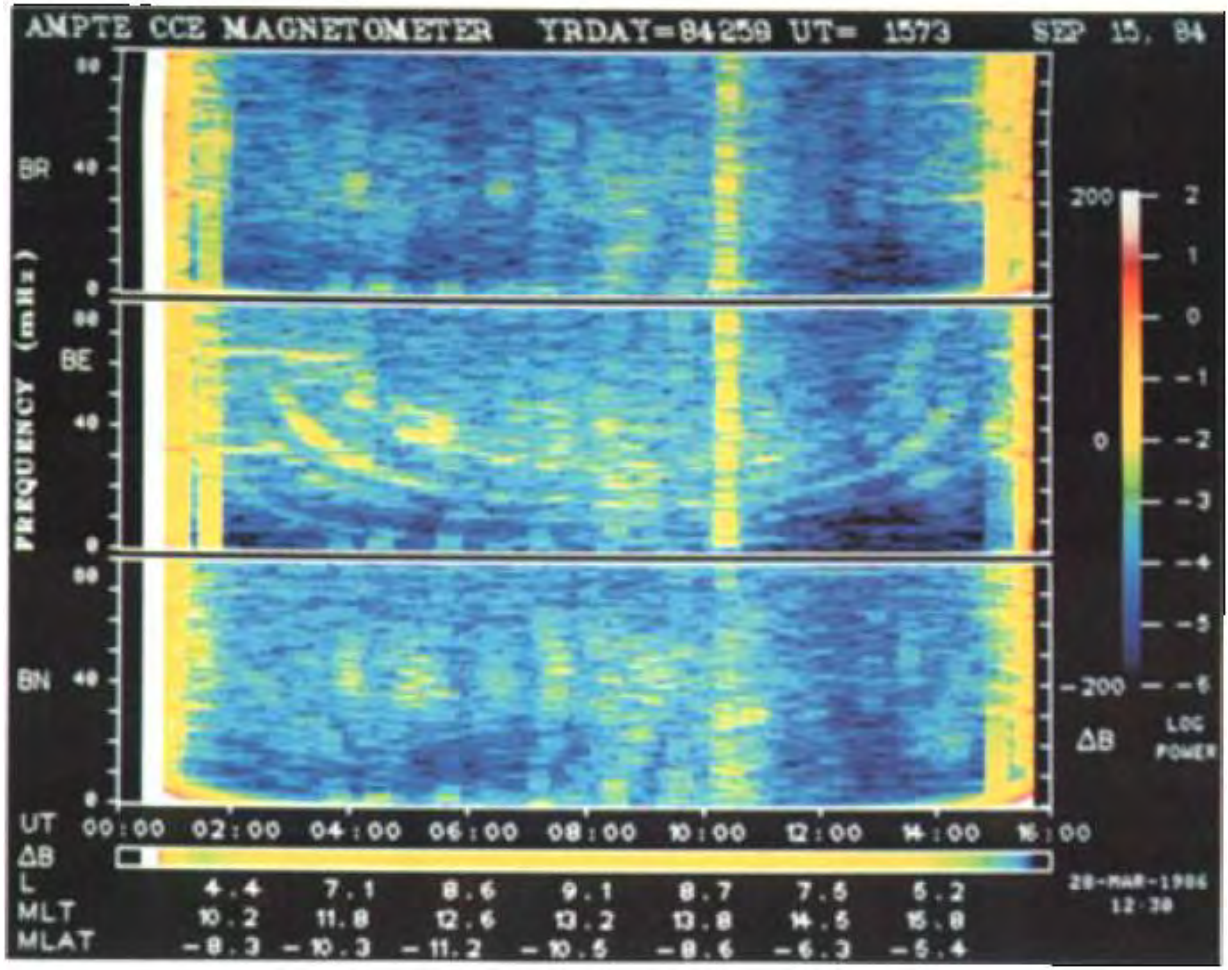

Martin Archer

# Heliophysics Audified: Resonances in Plasmas

- NASA grant to adapt MUSICS methodology to a US audience with more user-friendly tools / GUI
- We beta-tested new tools with citizen scientists: high school students part of teen librarian program, university students and researchers. As of today, the GUI is ready!

# Heliophysics Audified: Resonances in Plasmas

- Science Question: “Under what conditions is the continuum of standing Alfven waves – i.e., all harp strings playing at once – excited in the Earth’s magnetosphere?”
- Progress in addressing this question has been made with past models and satellite measurements, but we still can’t reliably predict what driving conditions will yield the full harp, a few harp strings, or no obvious activity.
- We’re using a large dataset from NASA’s THEMIS mission




Engebretson et al., 1986

# How to Get Involved

## Heliophysics Audified: Resonances in Plasmas

https://listen.spacescience.org

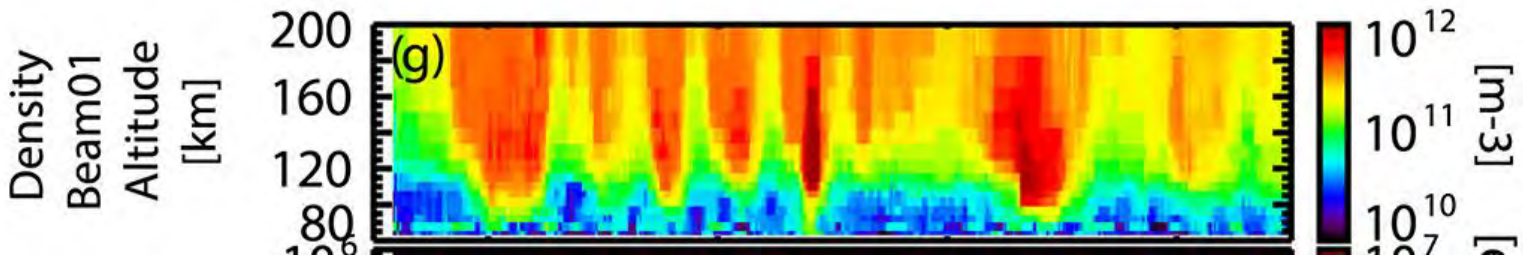
We need your help!

Ham radio operators are experts in audio analysis.

You can learn more about the project at the link above, and sign up to help identify harp events and/or provide feedback on our audio analysis tools

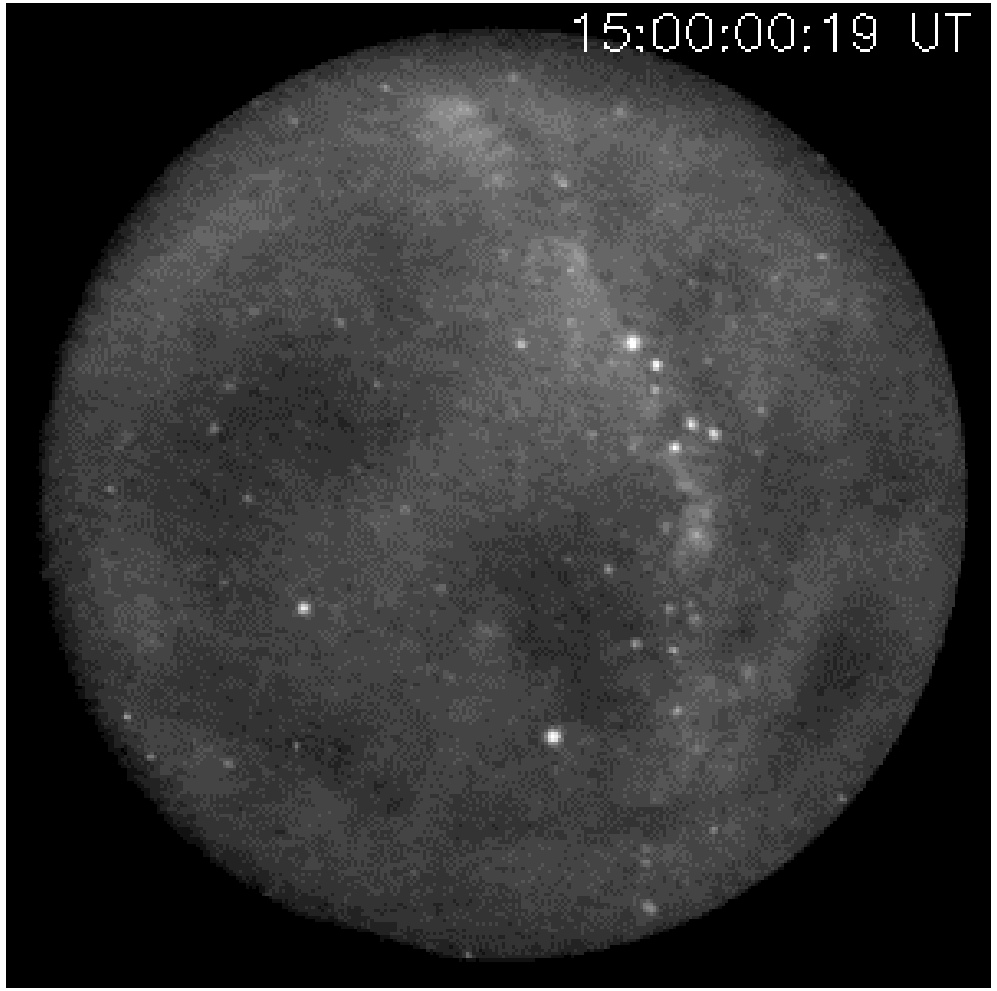
# Effects on the ionosphere: Connections with HamSCI science questions

- ULF waves deposit massive amounts of energy in the ionosphere → time variations in the aurora, ionospheric electron densities,…
  - Can these ionospheric impacts affect radio wave propagation?
- ULF waves modulate the growth of whistlers and other VLF waves
  - Do ham operators hear whistlers and other VLF waves come and go every few minutes? If so, when and where?
- Many other connections relevant to HamSCI science questions, “How does the ionosphere respond to inputs from space…?” and possibilities for future study




[Wang et al., 2020]

[Motoba et al., 2021]



# Summary

- Audification techniques have been applied to satellite datasets to study magnetospheric ULF waves
- Discovery of new phenomena, rapid exploration of large datasets
- We need the amateur radio community's help to identify ULF waves in NASA satellite data!
- Many areas for future collaboration with the amateur radio community in understanding ULF wave effects on the ionosphere, whistler waves,…

Future work: Audification of other satellite and ground-based datasets to study other plasma wave activity

Sign up to help at **listen.spacescience.org**
**Click "Get Involved"**

# Why don’t Heliophysics researchers use audio analysis?

- Our work addresses the challenges in using sonification methods identified in Zanella et al., [2022] – “(1) a lack of training and familiarity in sonification and (2) a lack of standardization, evaluation and dissemination” – but more work with other datasets and wave modes is needed
- The protocol we’ve used can readily be adapted to other Heliophysics datasets: standard data processing methods implemented in open-source python code, identification of the ideal audification parameters using iterative process (can be individual researcher or large group), using a combination of audio and visual inspection in GUI to identify expected and unexpected patterns
- **Why don’t Heliophysics researchers use sound as an analysis tool? Are there ways you can incorporate audified/sonified time series in your own work?**

# Further Reading

Alexander, R. L., O'Modhrain, S., Roberts, D. A., Gilbert, J. A., & Zurbuchen, T. H. (2014). The bird's ear view of space physics: Audification as a tool for the spectral analysis of time series data. Journal of Geophysical Research: Space Physics, 119, 5259– 5271.

Archer MO, Cottingham M, Hartinger MD, Shi X, Coyle S, Hill ED, Fox MFJ and Masongsong EV (2022) Listening to the Magnetosphere: How Best to Make ULF Waves Audible. Front. Astron. Space Sci. 9:877172. doi: 10.3389/fspas.2022.877172

Archer, M. O., Hartinger, M. D., Redmon, R., Angelopoulos, V., Walsh, B. M., & School Year 12 Physics students, Eltham Hill (2018). First results from sonification and exploratory citizen science of magnetospheric ULF waves: Long-lasting decreasing-frequency poloidal field line resonances following geomagnetic storms. *Space Weather*, 16, 1753– 1769. https://doi.org/10.1029/2018SW001988

Zanella, A., Harrison, C.M., Lenzi, S. *et al.* Sonification and sound design for astronomy research, education and public engagement. *Nat Astron* (2022). https://doi.org/10.1038/s41550-022-01721-z

Coming soon: United Nations Office of Outer Space Affairs: Space for Persons with Disabilities report on sonification